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Michael J. Sander
NASA Headquarters, Washington, D.C.

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Mr. Michael J. Sander
NASA Headquarters, Washington, D.C.

NASA is now in the early operational phase of the Shuttle Program. The STS-5 mission has, for the first time, conducted reimbursable commercial satellite deployments, while STS-6, -7, -8, and -9 continue the process of settling into an "operational mode." With the onset of this phase of Shuttle operations, it is appropriate to reexamine the structure of the NASA R&D STS payload program. Throughout the years from 1975 to 1981, program office attention has been focused on the first few R&D payloads, notably the OSTA-1 payload which contained a collection of Earth resources-oriented experiments, flying on the second Shuttle flight; the OSS-1 payload which examined the immediate Shuttle electromagnetic, gas, and particulate environment; and the Spacelab 1 and 2 missions whose primary purpose is the engineering verification of the Spacelab system, while, at the same time, obtaining significant scientific data.

New methodologies in experiment contruction, management of Principal Investigators and their contracts, new techniques of payload development and a whole new style of payload engineering and assembly have accompanied the onset of the Shuttle era of scientific exploitation of the space environment. Although these changes have resulted in the construction of lower cost instruments, one notable characteristic of this new style of doing business is the increased number of interfaces required to design, assemble and fly a payload. At a minimum, four NASA centers are involved in implementing any NASA STS R&D payload: the mission management center (which can be any NASA center), the Kennedy Space Center, the Marshall Space Flight Center and the Johnson Space Flight Center (figure 1). Although the proliferation of the NASA Centers involved in a given single payload has complicated the process of preparing the payload, the advantages of being able to retrieve instruments, modify them, retrieve science samples, and bring the scientist closer to the experiment have both offset the disadvantages of increased organizational complexity of each of the missions and provided an opportunity for a class of investigations intermediate between free-flyers and rocket/balloons.

With two major science flights now behind us, and with the first Spacelab flight in the assembly and verification stages at KSC, we should reexamine the Spacelab payload process to see if the current approach is resource optimized. The experiences associated with multi-disciplinary missions, notably Spacelab 1, suggest that mixing science disciplines which have conflicting requirements, for example Earth-looking and deep space-looking experiments, significantly compounds the complexity (cost) of a mission. These experiments have intrinsically different requirements in pointing, data management, operation time, crew interaction, power profile and many other aspects of Shuttle resources. The idea of focusing on a series of discipline-unique or discipline-emphasis laboratories is, in fact, an idea which has its roots in the early planning phases of the science use of the Shuttle;

therefore, one highly attractive view of the current payload inventory is to sort the candidate missions into discipline payloads or laboratories. Eleven such laboratories suggest themselves. These are: 1) the Space Biomedical Laboratory (formerly known as Spacelab 4); 2) Space Plasma Laboratory (formerly known as Spacelab 6); 3) the Shuttle telescopes for ultraviolet astronomy flights (Astro) (formerly known as OSS-3, -4, -5, -6, and -7); 4) the Shuttle High Energy Astrophysics Laboratory (formerly known as OSS-2); 5) the Shuttle Infrared Telescope Facility; 6) the Solar Optical Telescope; 7) a Materials Sciences Laboratory; 8) the Environmental Observations Mission; 9) the Shuttle Radar Laboratory; and 10) the Payload of Opportunity Carriers. One additional laboratory, the International Microgravity Laboratory, a complementary combination of biology and materials processing investigations, is also currently being considered as a member of this set.

DISCIPLINE LABORATORY CHARACTERISTICS

A discipline laboratory as discussed here has the following characteristics:

a) a collection of compatible science instruments built assuming Spacelab interfaces,

b) regularly flown at intervals on the order of 6 months to 2 years,

c) designed to allow evolution of individual instruments and the addition/deletion of instruments without redesign of the entire payload and mission. Instruments can be either PI-class instruments constructed by a Principal Investigator (primarily a single investigation) or facilities (a resource device for multiple instruments).

d) not disassembled from the Spacelab hardware between missions,

e) possibly evolving in the long term, to a low earth orbiting facility (the Space Station).

A distinction is made between an instrument and an experiment. Clearly, most instruments can be used to conduct a variety of experiments. As part of a Discipline Lab, an instrument becomes an experiment resource, to be flown as is or modified according to the direction of the sponsoring Science and Applications discipline organization. Experiment solicitations, a discipline organization responsibility, will have to be couched in terms which allow maximum use of the existing instrument inventories without discouraging acquisition of new instruments or modification of existing instruments. This type of evolution is, in fact, encouraged but will be bounded by the constraint of the budget in the NASA/Office of Space Science and Applications (OSSA).

The evolution process must contain a feedback mechanism which allows the results of one flight to impact the plan a subsequent flight. This approach implies a great deal of modularity for each instrument from a hardware, software and operational point of view. The size of the allowed impact is controlled by the dollar resources available, the flight interval, the flexibility of the laboratory design, and the capability of the total STS/Spacelab/Payload system to react to new inputs.

Experiments for the reflights are typically chosen with new Announcement of Opportunities (AO's), or "Dear Colleague" letters with the rate of evolution in any given laboratory limited (and defined) by funds available for new instrumentation, or instrumentation modification. The long term view for most of the laboratories is to develop hardware, as appropriate, suitable for long duration placement in Earth orbit within the context of the Science and Applications program and the Space Station architecture.

In this evolutionary laboratory approach to flight payloads, the instruments and laboratories should be designed with repair/refurbishment considerations in mind, and multiple flights become an integral part of the program approach. The use of category B for facility-class laboratory elements, such as Research Animal Holding Facilities (RAHF), Solar Optical Telescope (SOT), or Shuttle Infrared Telescope Facility (SIRTF), remains a major case-by-case trade-off.

A prime consideration for a discipline laboratory is the attention paid to its total lifetime cost. Given reflight as a major feature, its cost can be broken down into:

1. instrument development
2. experiment development
3. laboratory design
4. laboratory assembly/integration
5. mission operations design
6. mission operations
7. data analysis
8. instrument refurbishment
9. laboratory reverification
10. mission operations redesign
11. reflight mission operations
12. reflight data analysis

Cost items 1 through 7 are initial flight cost elements and 8 through 12 are reflight cost elements. Several independent estimates (OSS-1/OSS-1 reflight, and OSS-3/OSS-4) have shown that reflight costs are on the order of 10% to 20% of the initial flight costs assuming minor instrument change or refurbishment. It is likely that the laboratory design which minimizes costs for only items 1 through 7 may be quite different than the design which minimizes items 1 through 7 plus repetitions of items 8 through 12.

The systems design approach for each laboratory must take into account the ability to remove a single instrument and replace it with either a different instrument or an updated version of the removed instrument, which may or may not have the same engineering envelope. Ultimately, this procedure may have to be performed in orbit. Thus, the laboratory design must provide margins for growth and change. As an example, the data flow management must take into account some concepts akin to packet telemetry to avoid a massive spacecraft and ground reprogramming effort each time an instrument is modified, replaced or upgraded.

DISCIPLINE LABORATORY DESCRIPTIONS

The table below relates the current acronyms for the planned missions to their new Laboratory designators. Figure 2 indicates the Laboratory planned flight schedule.

1. Space Biomedical Laboratory (SBL): SBL is currently conceived to be a Spacelab double module having as its initial hardware the equipment associated with the 25 experiments now selected for the Spacelab 4 mission.

   The SBL currently has two Research Animal Holding Facilities (RAHF) and a General Purpose Work Station (GPWS) as its prinicpal multi-use facilities. It also includes such multi-user systems as a physiological monitoring system, refrigerators, freezers and many other, smaller items of hardware which have broad applicability to studies on human, animal, and plant subjects on 0-g. Planning is beginning for a follow-on mission (now called Spacelab 10) approximately 2 years later.

2. Space Plasma Lab (SPL): The Space Plasma Physics science community has been one of the great advocates for the use of the Shuttle as a scientific platform for the examination of the near-Earth environment, its interaction with Earth's atmosphere and as a platform for performing active experiments. Originally designated Spacelab 6, the Space Plasma Physics Laboratory is planned for launch in either 1987 or 1988.

Ten major instruments are being defined for the SPL mission series. The payload configuration could range from a single pallet arrangement on the first mission to two Spacelab pallets and a single Spacelab pressurized module on subsequent missions. The SPL mission series has involvement with the Japanese and the French by way of their Spacelab 1 instruments, which are also candidates for the SPL, and with the Canadians who have budgeted for three major instruments in the SPL instrument complement. The laboratory is currently undergoing feasibility studies and will soon transition into Phase B definition study. Final instrument selection for the first flight will be made in 1983.

The principal objective of the SPL mission series is to study the role that electromagnetic waves and plasma interactions play in the dynamics of Earth's magnetosphere and other natural plasmas. The SPL complement of active experiments forms a spaceborne laboratory which cannot be replicated on Earth because of the necessity for having confining walls in terrestrial laboratories. These active investigations involve the use of controlled inputs of electromagnetic waves, particle beams and plasmas to stimulate on a small scale those phenomena occurring in nature.

3. <u>Astronomy Research Laboratory (Astro)</u>: Astro is a UV astronomy laboratory with a one-meter telescope and two smaller telescopes to perform UV spectroscopy, imaging and polarimetry. The three telescopes are mounted to a central support spur, provided with the capability for image motion compensation and guided by the Spacelab Instrument Pointing System (IPS) attached to two Spacelab pallets. The astronomy community had identified a long list of objects (including Halley's Comet) which should be systematically photographed and examined with these instruments. The basic Astro mission calls for one flight and two subsequent reflights. The field of view of Astro is substantially greater than the Space Telescope, suggesting that one of the objectives is to act as a pathfinder for objects to be examined by the Space Telescope over the course of its mission. The first flight of Astro is currently scheduled for March 1986 (coincident with arrival perihelion of Halley's Comet). One-half the Shuttle cargo bay will be subscribed by this mission. Eventually, the spectral range and other capabilities of this laboratory may be extended as the scientific and technical program evolves.

4. <u>Shuttle High Energy Astrophysics Laboratory (SHEAL)</u>: SHEAL is a conceived set of four instruments whose sensitivities represent approximately a three orders of magnitude improvement in capability over previously flown x-ray instruments. The four instruments currently being considered are a Diffuse X-ray Spectrometer, a Large Area Modular Array of Reflectors, a Broad Band X-ray telescope and Cosmic Ray Nuclei Experiment. Configurations of the SHEAL will allow the addition of other high energy instruments in the future. Assuming a start for this payload in FY-84, preliminary studies indicate that a flight in late 1987 is possible.

5. <u>Shuttle Infrared Telescope Facility (SIRTF)</u>: SIRTF has been under study for approximately 10 years. SIRTF is a one-meter class, cryogenically cooled, infrared telescope facility. The telescope elements will be cooled to approximately 10 degrees Kelvin, and the instrument chamber to 2-3 degrees. No instruments have been selected yet for the SIRTF; however, an Announcement of Opportunity is planned for release before the

middle of 1983 to begin defining the initial flight instrument complement. SIRTF is viewed as a facility-class device to be flown a number of times with an evolving complement of scientific instruments and eventually to be placed on the Space Station or in the Space Station environment. The flight hardware phase is planned to begin with the first flight contemplated in 1990.

6. <u>Solar Optical Telescope (SOT)</u>: SOT, another one-meter class telescope facility, will be the mainstay of the solar physics community through the next decade. The SOT program has just completed a contractor selection phase and feasibility study for the telescope assembly and is now in the definition phase. An instrument complement for the first flight has been selected for detailed definition. SOT will achieve a spatial resolution of 0.1 seconds of arc on the sun. From the near infrared to the far ultraviolet, and the scientific instruments will examine both the morphology of the complex lower solar atmosphere (photosphere and chromosphere), as well as examine the specific plasma properties, such as temperatures, densities and velocity and magnetic fields. SOT also is intended to have an evolving scientific payload and to transition into a permanent role in association with the future Space Station.

7. <u>Materials Sciences Laboratory (MLS)</u>: Materials Science has been operated for a number of years based on an assumption that devices similar to the current Material Experiment Assembly (MEA-A) will be the basis for Materials Science experiments in space. The first flight of the MEA-A is scheduled for June 1983, with subsequent reflights every 6 months. The MEA-A is capable of supporting three rocket-type experiments with limited power (30 kwh) supplied by batteries. It is clear that this is inadequate for the long term and certainly does not represent a particularly aggressive Materials Sciences test program in space. Studies are now underway to define a next generation carrier for these Materials Processing devices. Materials Sciences is just completing development of two major facilities which operate within the Spacelab pressurized module. Potential use of existing facilities developed by Germany and the European Space Agency presents another avenue currently being explored.

8. <u>Environmental Observations Mission (EOM)</u>: EOM is a concept for atmospheric and solar measurements utilizing existing instruments developed for the OSS-1, Spacelab 1, and Spacelab 3 missions. These will be mounted on a Spacelab pallet and will be flown approximately once per year to serve as a calibration facility for instruments currently in orbit and planned for orbit as part of the Upper Atmosphere Research Satellite (UARS) program.

9. <u>Shuttle Radar Lab (SRL)</u>: SRL is the outgrowth of the highly successful SIR-A flight on the OSTA-1 mission. The SRL will attempt to study combinations of radar beam incidence angle, polarization, and frequency to determine the optimum combination of signals best suited for specific scientific studies and mapping of the Earth's oceans and land surface. The next flight of the Shuttle Radar Laboratory, formerly called the OSTA-3 mission, will take place in mid-1984. On this mission, the prime instrument, the Shuttle Imaging Radar (SIR), will be upgraded with a tilting antenna. Follow-on flights will then take place as resources permit. The third flight, with a version of SIR, which includes a C-band capability, is currently scheduled for 1986. This mission could be the first NASA mission utilizing

the Vandenberg Air Force Base Shuttle launch facilities.

10. International Microgravity Laboratory (IML): IML will be utilized as an opportunity for foreign countries to participate in the Shuttle program, flying and reflying facilities which have been developed over the past years or which are being considered for future initiatives. Facilities like the German Materials Sciences Double Rack, the ESA Biorack and the Sled, would be flown on a cooperative basis. The United States would provide the flight opportunity and the required integration into the IML, and the cooperating nations would provide scientific facilities. Access to these facilities will be made available to American investigators, thus minimizing the need for duplication of expensive experiment hardware.

    The IML will consist of a single Spacelab double module, with other Spacelab hardware behind the module as directed by the experiment needs. The concept of the IML is to allow U.S. scientists access to very costly foreign-developed facilities now in existence or on the drawing boards and, in turn, to provide scientists from other nations access to the Spacelab capability and repeated flight opportunities. Instrumentation for IML would be encouraged toward the development of laboratory equipment suitable for placement in the Space Station.

    The current plan is to first fly the IML in 1987, with repeated flights on a schedule dictated by the development of additional experiments and Shuttle launch opportunities. As with the other laboratories, it is expected that the IML will slowly evolve with time and be designed on a modular facility basis allowing individual facilities to be updated without reengineering the entire IML.

11. Payload of Opportunity Carrier (POOC): The POOC is a low cost means of placing experiments aboard the Shuttle in the cargo bay. The POOC would be integrated and prequalified to support experiments along a number of experiment 'stations' on its structure. The carrier would have access to Orbiter power, cooling, and data management facilities. The POOC would be in place at KSC waiting for instruments which meet the interface presented by the POOC, and a launch slot. The POOC is designed to take minimum Shuttle payload bay sill space and be capable of being placed at the last minute on the Shuttle should other payloads drop out. Individual instruments looking for extended 0-g stay time and operation that can be conducted with little dependence on the Shuttle, the Payload Operations Control Center, the Level IV integration or other STS resources would be ideal candidates. Highly integrated instrument complements or very complex missions requiring a great deal of interaction and preplanning are not ideal candidates for the POOC. The POOC is seen to fill the gap between the Get-Away-Special (GAS) cans and the highly integrated, discipline laboratories. It, thus, provides more than just structural support, significantly reducing the instrument developer's burden of providing power and data management capabilities, but at the same time presenting limitations in the flexibility of the interface presented to the instrument.

The Spacelab, once thought to be a means for almost casual, low cost space-based investigations, has been shown to be extremely flexible, but unfortunately more costly than originally planned. The increased costs are due in part to the complexity attendent any manned system and the redundancies and safety related analysis which must be part of a manned program. These increases can be offset by viewing the planned payloads as a set of laboratories which are reflown at regular intervals rather than being entirely new collections of instruments. Changes are introduced between flights, but in a systematic, paced manner rather than a total reconfiguration. The interfaces between the instruments and the Spacelab are designed to promote more independence in the instrument and less reliance on services in the Orbiter and Spacelab. By urging more independence onto the individual instruments, upgrades and instrument changeout between missions becomes significantly less expensive. Costs are further decreased by allowing reflights of instruments on a regular basis, providing some relief on risk of failure. Since this strategy reduces the overall Spacelab flexibility, another carrier, the Payload of Opportunity Carrier, is being examined as a means to provide power/structural/command and data support for investigations willing to meet very fixed interfaces and minimal integration and test preparation cycles.

The Discipline Laboratory and Payload of Opportunity Carrier concepts represent a evolutionary step in the use of the STS for Science and Applications payloads.

Spacelab Flight Division

Typical Payload Organization

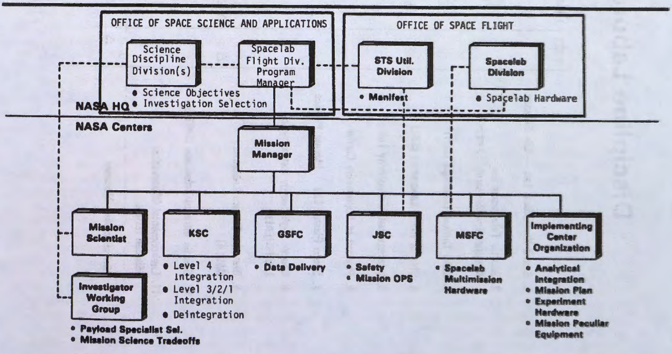

Figure 1

Discipline Laboratory Overview

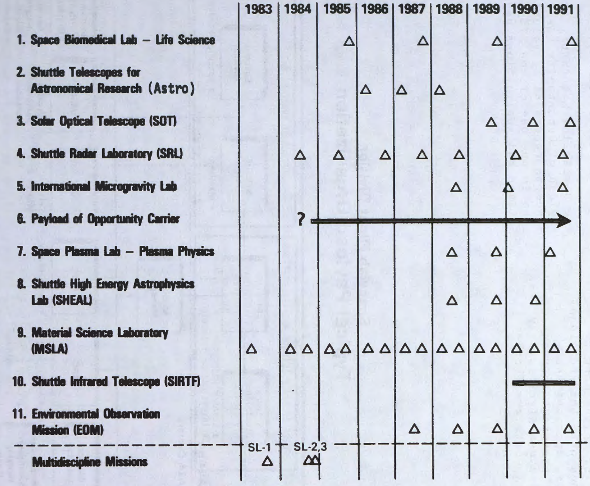

Figure 2